The analysis of cross-sections of proton and deuteron induced reactions on tin isotopes at the beam energy of 3.65 GeV/nucleon.

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In the given paper the total inelastic cross-sections of the reactions of protons and deuterons on nuclear targets of enriched tin isotopes were compared. The factorization of cross-sections of reactions was discussed. Furthermore, the comparison of theoretical estimations on total inelastic cross-sections with corresponding experimental ones was made.

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I. INTRODUCTION

In recent years, there has been a considerable interest in the study of high energy proton-nucleus and nucleus-nucleus collisions. It has been suggested that such interactions, in addition to extending our knowledge of nuclear reactions, might also shed some light on the fundamental questions of nuclear physics.

The interest in the study of spallation reactions has been revived primarily by the advent of new projects in nuclear technology, in particular (existence) by investigations on the accelerator-driven subcritical nuclear power reactors. It is becoming increasingly evident that, besides having a rigid theoretical background, the scientists in charge of these projects need to have comprehensive information concerning the properties of the spallation reactions. It is assumed that of special interest might be to know to know how these properties vary with the parameters of the collision. Currently there are a number of theoretical descriptions of interaction of high-energy particles with nuclei. The standard INC+evaporation model describes well the spallation reactions in the wide range of energy of projectile [1]. Likewise, the Glauber model [2] also provides quite a sufficient description of the inelastic scattering of high energy particles on atomic nuclei. The goal of this paper is to study the reaction mechanism by comparing the total inelastic cross-sections of reactions induced by protons and deuterons on enriched tin isotopes.

II. EXPERIMENTAL SETUP AND DISCUSSION

The experiments were conducted on the Nuclotron of JINR [4, 5]. The targets of enriched tin isotopes (^{112}Sn, ^{118}Sn, ^{120}Sn and ^{124}Sn) were irradiated with the extracted deuterons beam accelerator. For the study of cross-sections the method of induced activity was used. Characteristic gamma spectra were measured on high-purity germanium detectors. The energy of protons and deuterons beams was 3.65 GeV/nucleon. On average, 90 residual nuclei were obtained from each target. The systematization was conducted using 10 parametrical formula [6].

$$\sigma(Z, A) = exp(a1 + a2 \cdot A + a3 \cdot A^2 + a4 \cdot A^3 + (a5 + a6 \cdot A + a7 \cdot A^2)|Z_p - Z|^{a8}) \tag{1}$$

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where $Z_p = a9 \cdot A + a10 \cdot A^2$ is the most probable charge at the given mass number A. The parameters $a1, a2, a3, a4$ determine the shape of the mass curve, the parameters $a5, a6, a7$ determine the width of the charge dispersion curve and the parameters $a9, a10$ determine the position of the peak of the distribution of isobaric yields. Fitting was carried out by the least square method by the program ÇFUMILIÈ. Total inelastic cross-sections for targets are defined as the sum of the isobaric cross-sections $\sigma(Z, A)$.

The estimated total inelastic cross-sections with the theoretical calculations are presented in Table. Figures 1 and 2 show the experimental total inelastic cross-section as well as the theoretical calculations on the mass number of targets. Theoretical estimates are made via the standard cascade-evaporation model [1], the Glauber model [2] and an empirical expression traditionally used for the data interpretation based on geometrical predictions [8]:

$$\sigma_{tot} = \pi r_0^2 (A_p^{1/3} + A_T^{1/3} - b)^2 \tag{2}$$

where b is overlap parameter, A_p, A_T are the mass numbers of projectile and target. In Glauber approach [2] the inelastic cross-section of hadron-nucleus interaction is given by the expression:

$$\sigma_{hA}^{inel} = \int d^2b[1 - exp(-\sigma_{hN}^{tot} \int_{-\infty}^{\infty} \rho(\vec{b}, z)dz)] \tag{3}$$

where $\rho(\vec{b}, z)$ is one particle nuclear density, σ_{hN}^{tot} cross-section of the interaction of incident hadron h with nucleus nucleon N. In calculations the fermi parametrization was used for $\rho(\vec{r})$ with parameters from [3].

As is seen from the Table I and Figures 1 and 2, for proton-nuclear reactions theoretical calculations more realistically describe the experimental results. In the case of the deuterons-induced reactions, most of experimental points lie above the theoretical curves, although within the errors they describe the experimental results. This can be explained by the fact that in the theoretical calculations some of the effects, related to the nucleon composition of the projectile, may be not considered.

The concepts of factorization have been developed for the interpretation of the reaction induced by high energy particles and nuclei. For the beam energies greater than 2 AGeV single particle inclusive spectra of target fragments were predicted to depend on the nature of projectile via the total reactions of cross-section. The single particle inclusive reaction can be written as $P + T \to F + X$, where P and T correspond to the projectile and target, and F and X to the fragment, produced during the reaction, and anything else. If the hypothesis of factorization exists the cross-section for the product of target fragmentation F can be factorized to $\sigma_{T,P}^F = \sigma_T^F \gamma_p$, where γ_p is dependent only on the projectile. If we have proton- and deuteron-induced reaction we can write

$$\sigma^F(d + Sn)/\sigma^F(p + Sn) = \gamma_d/\gamma_p = R,$$

where R is a relative projectile factor. If the factorization hypothesis is valid, this factor should be equal to that of the total reaction cross-sections.

Figure 3 shows the ratio (R) of cross-sections of residual nuclei in deuteron-nucleus reactions to the proton-nucleus reactions for all targets. As can be seen for targets similar mass to the natural composition of the isotope (^{118}Sn,^{120}Sn) these relations on average are in agreement with published data (R=1,6) [9]. For targets ^{112}Sn and ^{124}Sn cross-section the ratio are different, in particular, for ^{112}Sn, this ratio is 1.3, and for ^{124}Sn, it is 1.9. One should expect that the ratio of the cross-section of the residual nuclei for deuteron- and proton-nucleus reactions is sensitive to the isotope composition of the target-nucleus. In the Table I, together with the total inelastic cross-section are the radii of the projectile and the target nucleus, as well as the effective impact parameters of interaction computed according to the formula (2). Since $1/2(R_p + R_T) < b$ for all the targets we can conclude that the collision is peripheral. This fact can be explained as follows. The difference in the interaction of deuterons and protons should be revealed in the transferred excitation energy. This process is dependent on the collisions conditions and the impact parameters values. In peripheral collisions at large impact parameter the probability of the whole deuteron interaction is very low. Taking into account the low coupling energy in deuteron it can be presented that in this case only one participant nucleon from deuteron interacts with target. The target spallation , which takes place at relatively low excitation energies, is more probable in these cases. The cross sections with low number emitted nucleons are the largest and carry the largest statistical weight. The experimental cross sections do not change in energy range about several GeV, at least for proton-induced reactions. In other words spallation cross-sections at high energy are saturated in regime of limiting fragmentation. Taking into account the above mentioned discussion it is clear, that cross-section ratio in the target spallation range ($A \geq 60$ amu) will be very similar for proton- and deuteron-induced reactions at the energies of a few GeV. On average $\sigma_d(A, Z)/\sigma_p(A, Z) = 1.0 \pm 0.1$ for all targets. At higher excitation energies the multifragmentation phenomenon appears, these cases are related to the more central interactions of the incident

projectiles and target. The cross sections of these reactions are small and statistical uncertainties are essentially increased (as can be seen from fig. 3). The statistical weights of these collisions are low. For this reason they do not affect on the average values of the calculated impact parameter. But these cases can present the deuteron deposit in the total interaction process. The cross-section ratio in the case of deuteron to proton for these collisions essentially exceeds the value near one in spallation range $\sigma_d(A, Z)/\sigma_p(A, Z) = 2.0 \pm 0.2$ for all targets.

III. CONCLUSION

The total inelastic cross sections for proton-nuclear and deuteron-nuclear reactions with theoretical calculations were compared. The data received permits to conclude that for proton-nuclear reactions theoretical calculations more realistically describe the experimental results. The impact parameter of interaction of protons and deuterons with tin targets were obtained. According to the values of these parameters we conclude that the collision is peripheral.

Acknowledgment

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[1] V.S. Barashenkov, V.D. Toneev, Interaction of high-energy particles and atomic nuclei with nuclei, Moscow, Atomizdat, 1972.
[2] R.J. Glauber. High Energy Physics and Nuclear Structure. N.Y.: Plenum Press, 1970.
[3] P.V. Murthy et al., Nucl. Phys. B **92**, 269 (1975)
[4] A.R. Balabekyan, A.S. Danagulyan, J.R. Drnoyan, et al., Physics of Atomic Nuclei **68**, 171 (2005)
[5] A.R. Balabekyan, A.S. Danagulyan, J.R. Drnoyan, et al., Physics of Atomic Nuclei **69**, 1485 (2006)
[6] N.T.Porile, G.D.Coleand C.R.Rudy, Phys. Rev. C **19**, 2288 (1979).
[7] S. G. Mashnik, K. K. Gudima, M. I. Baznat, A. J. Sierk, R. A. Prael and N. V. Mokhov, Report, LA-UR-05-2686, Los-Alamos (2005).
[8] H. H. Heckman, D. E. Greiner, P. J. Lindstrom, et al., Phys. Rev. C **17**, 1735 (1978).
[9] P.Kozma PhD thesis p. 85 (1991) JINR, Dubna.

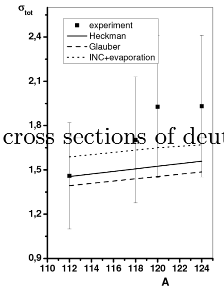


FIG. 1: Total inelastic cross sections of deuteron-nucleus interactions

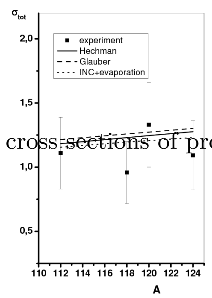
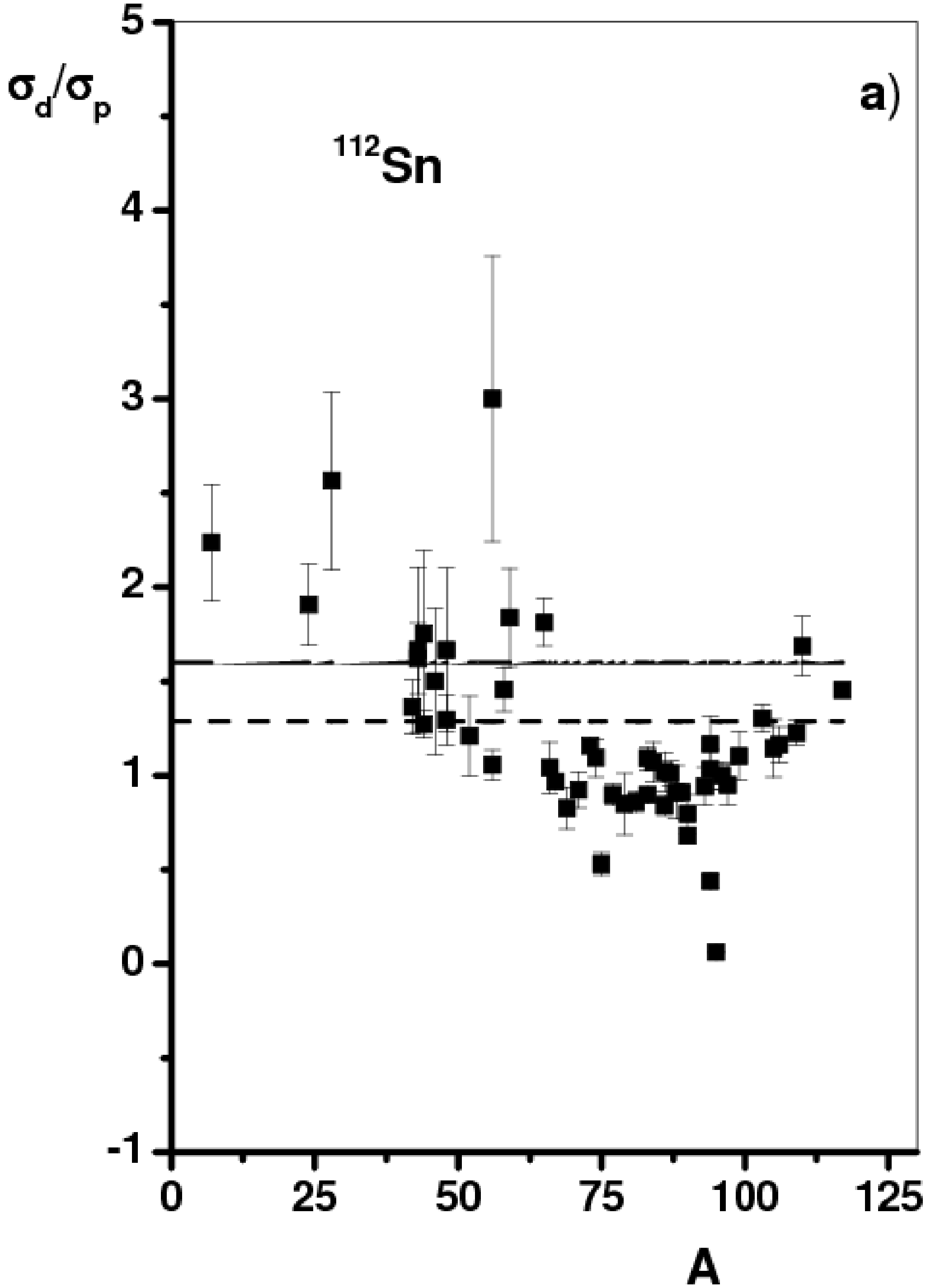


FIG. 2: Total inelastic cross sections of proton-nucleus interactions



σ_d/σ_p
a)
^{112}Sn
5
4
3
2
1
0
-1
0
25
50
75
100
125
A

Table. The total inelastic cross-sections of deuterons and protons induced reactions and the overlap parameters.

reactions	exp. bn	Heck. bn	Glauber bn	INC bn	R_p fm	R_T fm	parameter b fm
$p+^{112}Sn$	1.109± 0,27	1.183	1.215	1.155	1.37	6.604	6.43
$p+^{118}Sn$	0,951± 0,24	1.23	1.259	1.196	1.37	6.72	6.45
$p+^{120}Sn$	1.331± 0,33	1.246	1.273	1.207	1.37	6.757	7.35
$p+^{124}Sn$	1.092 ± 0,27	1.276	1.302	1.23	1.37	6.83	6.62
$d+^{112}Sn$	1.46± 0,36	1.455	1.393	1.588	1.73	6.604	7.84
$d+^{118}Sn$	1.704± 0,43	1.507	1.44	1.634	1.73	6.72	8.21
$d+^{120}Sn$	1.928± 0,48	1.525	1.455	1.65	1.73	6.757	8.4
$d+^{124}Sn$	1.931± 0,48	1.559	1.486	1.67	1.73	6.83	8.46